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TRANSIENT ANALYSIS OF WIND CONNECTED SYSTEM BASED ON DFIG

SOHIT SHARMA[1] & K. G. SHARMA[2]

[1]Research Scholar, Jagannath University, Jaipur, Rajasthan, India

[2]Associate Professor, Government Engineering College, Ajmer, Rajasthan, India

ABSTRACT

Increasing utilization of electricity requires evolving the new environment friendly and efficient techniques which fulfil the required demand and also have effective response during the various faults. According to the latest survey wind power generation is on top in category of renewable energy. This paper gives the brief idea about the types wind turbine generators and among these, this paper mainly focuses on doubly fed induction generator (DFIG). Thus we have compared the DFIG based wind power system of 9 MW connected to 120 KV grid with synchronous generator of same rating for single line to ground, double line and three phase fault. Both the models are simulated on MATLAB and various conclusions are made.

KEYWORDS: Transient Analysis, Wind Turbines, Doubly Fed Induction Generator, Synchronous Generator, Reactive Power

INTRODUCTION

With increase in use of gadgets leaving standard of life is enhancing which produces various diseases; because more comfort reduces our resistance power to fight against harmful virus thereby our immune system becomes week. One more important thing is that their uses also increases carbon footprint. These all are run by using electricity. Electric power is generally coming from thermal and nuclear power plants in India. Thermal power plants consumes large amount of coal which is available in limited quantity and also releases large amount of harmful gases. Nuclear Power Plants uses nuclear fuel, which emits harmful radiations. Both plants have great environmental issues. If these issues are not resolve, future of human being is not safe. In India total installed capacity of generating units is 258701.46 MW as on 31/01/2015. In this, contributions of thermal power plants are 180361.89 MW [1]. One method is to resolve these issues is that to reduce our dependency on these plants. Second one is to increases our dependency on renewable resources. Renewable resources are the resources by using them we generate energy without emitting pollution. By keeping environmental problems in mind, we have to opt safer and green way. This can be possible by using Green Technology.

Green technology includes various inventions and technologies that are environmental friendly, energy efficient, use non-conventional energy resources, conforming health and safety and focuses on three R's: recycle, reduce and reuse. Some of the examples of green technologies are use of non- conventional sources of energy like solar energy, wind energy, tidal energy etc [2]. Fig.1 form the Renewable 2014 Global status report, it shows that in the renewable energy sector wind power generation is on second position with the considerable amount of 2.9% sharing of all global electricity production.

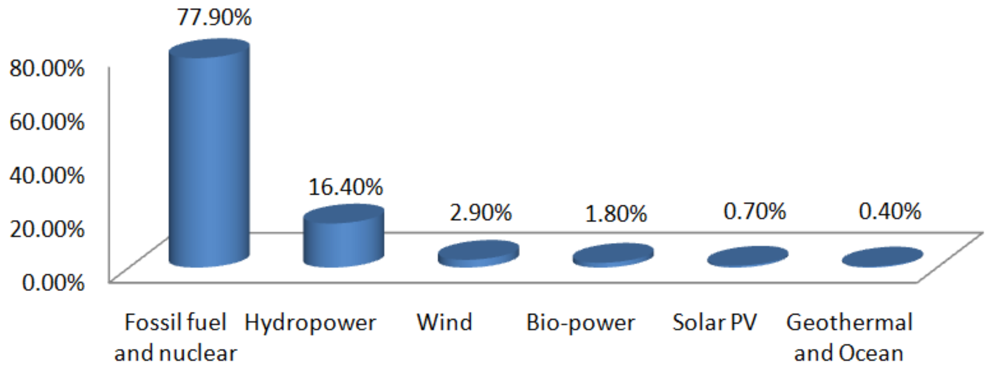

Figure 1: Shows the Sharing of Electricity Production

India has installed capacity of 31692.14 MW from renewable energy sources [1] and contribution of wind power is 22597 MW [3] as on January 2015.

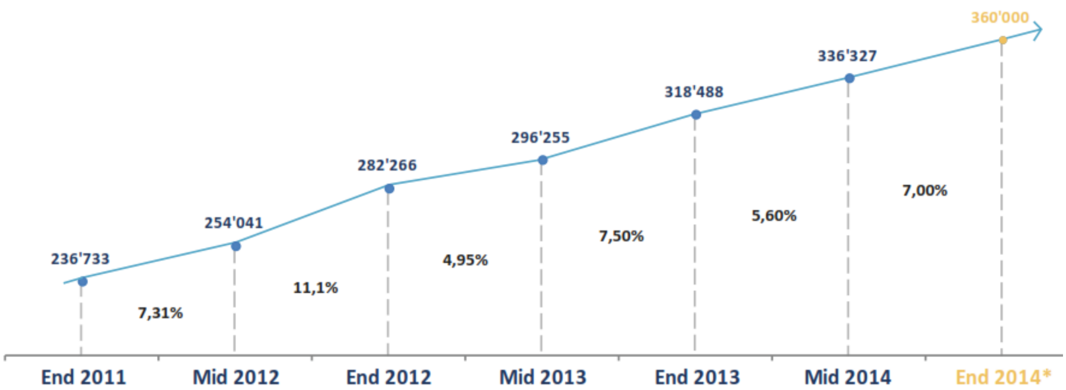

Figure 2: Total Installed Capacity of Wind Power in World during 2011-2014 [4]

According to the world wind energy report 2014 shows in figure 2, it is also clear that how wind power generation increases in world. At the end of 2014 total installed capacity of wind power is approximately to 360000 MW. From these values we can say that wind power generation contributes major portion in energy sector.

Power system stability is categorised into three types. These are steady state stability, transient stability and dynamic stability. Power system stability refers to regain its steady state after the disturbance. Transient stability involves the analysis of large amplitude of disturbance for small duration. Inertia of system plays an important role. Duration of study is 1 second or less then it. Because of large time constants control system components are too slow to respond hence they are not considered. In wind power generation, because of unpredictable nature of wind, output has large variations and impact should be concluded in transient analysis. Unpredictability of wind speed leads to more spinning reserve for wind mills in compare to thermal power plants which results in additional amount of inertia in system therefore transient analysis is important. [5]

WIND TURBINE GENERATOR

In the wind power generation, wind power is converted into electric power by using wind turbine. Basically there is no turbine system used in this design as such in thermal power plants, correct name for this is aerofoil- powered generator. Rotor blades are designed in such a way that as flowing wind comes in contact with rotor blades, aero dynamical

force is generated and rotor blades begins to rotate. This rotational mechanical power is applied to generator through gear mechanism.

Rotational mechanical power is a function of ρ (air density), A (area swept by rotor blades), v (wind speed) and C_P (power coefficient).

Rotational Mechanical $P_{out} = \frac{1}{2}\rho A v^3 C_p$ (1)

C_P is a function of β (blade angle) and λ (tip speed ratio) theoretically its value is less than or equal to 0.593. [6]

$\lambda = \frac{\omega R}{v}$ (2)

Where ω is turbine rotational speed and R is rotor radius.

Primarily wind turbine generators are divided into two parts, first one is fixed speed wind turbine and second is variable speed wind turbine. Based on types of generator and power electronics converter, these wind turbine generator further classified into five types. Type 1 Fixed speed squirrel cage induction generator, Type 2 Fixed speed slip ring induction generator, Type 3 Variable speed doubly fed induction generator, Type 4 Variable speed direct driven synchronous generator, Type 5 Constant speed synchronized generator.

Fixed speed and variable speed implies the speed of rotor of the generator. If the speed of rotor is constant then it categorised in fixed speed wind turbine generators and if the speed of rotor is variable in accordance with the speed of flowing wind then these wind turbines are known as variable speed wind turbine generator. Major drawback of fixed speed system is that, the speed of rotor is depends on the frequency of grid this is because the output of generator is directly connected to grid. Gear mechanism is placed between rotor blades and rotor. There is a continuous controlling of gear system so that rotor can rotate on constant speed. From the above classification DFIG is the better option because it is a variable speed system. Gear system is also present here but only for increasing the rpm of rotor.

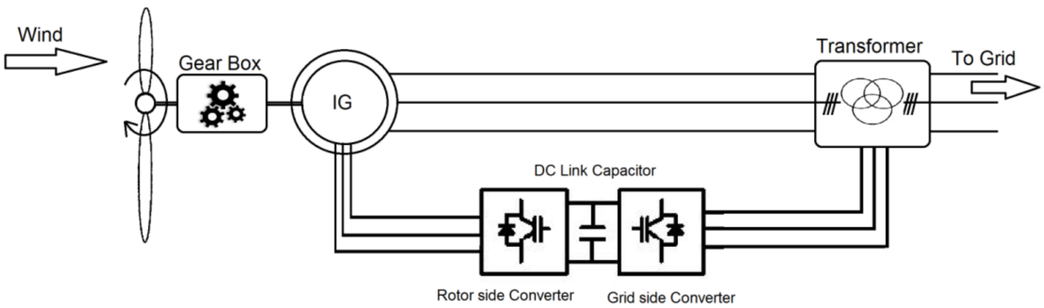

Figure 3: DFIG

In the DFIG, stator winding is connected to grid directly and rotor winding is connected to gird through back to back connected converter as shown in figure. Converter connected to rotor known as rotor side converter and converter on grid side known as grid side converter. Advantage of DFIG is that it works on both sub synchronous and super synchronous speed with range of $\pm 30\%$ of synchronous speed. Voltage source converter on rotor side can vary the voltage applied on rotor so that current changes in rotor winding and resulting into the controlling of torque. During the fault period rotor fed power circuit remains in operation and maintains the stator current in limit. Frequency fluctuations are

present in output because of unpredictable nature of wind but in DFIG these are completely eliminate. Conventional induction generator is a highly lagging load for reactive power but DFIG helps us to maintain the power factor nearly equal to unity [7].Active and reactive power flow is partially control by grid side converter. Active power is controlled by load angle and reactive power by voltage magnitude at grid side converter. Because of these merits DFIG widely used in wind power generation. This paper shows the nature of DFIG during the various faults.

MODELLING OF DFIG

Following equations are the basic equation of asynchronous machine in synchronous rotating reference frame. [8]

For Stator

$$\varphi_{ds} = X_s i_{ds} + X_m i_{dr} \tag{3}$$

$$\varphi_{qs} = X_s i_{qs} + X_m i_{qr} \tag{4}$$

$$v_{ds} = -R_s i_{ds} + \omega_s \varphi_{qr} - \frac{1}{\omega_{base}} \frac{d}{dt} \varphi_{ds} \tag{5}$$

$$v_{qs} = -R_s i_{qs} - \omega_s \varphi_{ds} - \frac{1}{\omega_{base}} \frac{d}{dt} \varphi_{qs} \tag{6}$$

For rotor

$$\varphi_{dr} = X_r i_{dr} + X_m i_{ds} \tag{7}$$

$$\varphi_{qr} = X_r i_{qr} + X_m i_{qs} \tag{8}$$

$$v_{dr} = -R_r i_{dr} + s\omega_s \varphi_{qr} - \frac{1}{\omega_{base}} \frac{d}{dt} \varphi_{dr} \tag{9}$$

$$v_{qr} = -R_r i_{qr} - s\omega_s \varphi_{dr} - \frac{1}{\omega_{base}} \frac{d}{dt} \varphi_{qr} \tag{10}$$

$$s = \frac{\omega_s - \omega_r}{\omega_s} \tag{11}$$

$$T_{em} = \varphi_{qr} i_{dr} - \varphi_{dr} i_{qr} \tag{12}$$

In the above equations d and q represent direct and quadrature axis, $(\varphi_{ds}, \varphi_{qs})$ represent the stator flux, $(\varphi_{dr}, \varphi_{qr})$ the rotor flux, (i_{ds}, i_{qs}) the stator current, (i_{dr}, i_{qr}) the rotor current, $(v_{ds}, v_{qs})$the stator voltage, $(v_{dr}, v_{qr})$the rotor voltage, R_s, R_r, X_s, X_r, X_m, s, ω_s, ω_r, ω_{base}, T_{em} means the stator resistance, rotor resistance, stator reactance, rotor reactance, mutual reactance, slip, synchronous speed, rotor speed, base frequency and electromechanical torque respectively.

For the simplicity two assumptions are assumed, first one is that in stator and in between inverter and grid electromechanical oscillations are neglected and second is that, control system used for rotor and grid side control have low time constant in comparison to transient analysis time scale therefore dynamics of current control is neglected. [8] From these assumptions above equations are converted into below equations.

Rotor side current I_r is divided into two components $i_{dr}^{(\phi)}$ and $i_{qr}^{(\phi)}$. First is in phase with φ_s stator flux linkage and

other is in quadrature with it. These components are in (d, q) synchronous rotating reference frame. $\emptyset$ is the angle between φ_s and reference frame. Grid side current I_a is divided into two components $i_{da}^{(\in)}$ and $i_{qa}^{(\in)}$. First is in phase with V_s stator voltage and other is in quadrature with it. These components are in (d, q) synchronous rotating reference frame. $\in$ is the angle between V_s and reference frame. The concluding equations of the model are as follow [8]

$$v_{ds} = -R_r i_{ds} + X_s i_{qs} + X_m i_{qr} \tag{13}$$

$$v_{qs} = -R_s i_{qs} - X_s i_{ds} - X_m i_{dr} \tag{14}$$

$$i_{dg} = i_{ds} + i_{da} \tag{15}$$

$$i_{qg} = i_{qs} + i_{qa} \tag{16}$$

$$\varphi_{ds} = X_s i_{ds} + X_m i_{dr} \tag{17}$$

$$\varphi_{qs} = X_s i_{qs} + X_m i_{qr} \tag{18}$$

$$\emptyset = arctan\left(\frac{\varphi_{qs}}{\varphi_{ds}}\right) \tag{19}$$

$$i_{dr} = i_{dr}^{(\emptyset)} cos(\emptyset) - i_{qr}^{(\emptyset)} sin(\emptyset) \tag{20}$$

$$i_{qr} = i_{dr}^{(\emptyset)} sin(\emptyset) + i_{qr}^{(\emptyset)} cos(\emptyset) \tag{21}$$

$$\in = arctan\left(\frac{v_{qs}}{v_{ds}}\right) \tag{22}$$

$$i_{da} = i_{da}^{(\in)} cos(\in) - i_{qa}^{(\in)} sin(\in) \tag{23}$$

$$i_{qa} = i_{da}^{(\in)} sin(\in) + i_{qa}^{(\in)} cos(\in) \tag{24}$$

$$T_{em} = X_m\left(i_{dr} i_{qs} - i_{qr} i_{ds}\right) \tag{25}$$

DC Link Voltage Model

Grid side converter and rotor side converter are connected back to back through a capacitor of C value. P_{dc} is the power supplied to capacitor and W_{dc} is the stored energy in DC link

$$W_{dc} = \int_0^t P_{dc}\, dt = \frac{1}{2} C V_{dc}^2 \tag{26}$$

$$\frac{dV_{dc}}{dt} = \frac{P_{dc}}{CV_{dc}} \tag{27}$$

Here V_{dc} is the voltage on capacitor. P_{em} Electro mechanical power, P_{rr} rotor losses, P_{rs} stator losses and P_g total power output these values are calculated from the help of following equations and from these parameters P_{dc} is calculated. [8]

$$P_{em} = T_{em}\omega_r \tag{28}$$

$$P_{rr} = R_r\left(i_{dr}^2 - i_{qr}^2\right) \quad (29)$$

$$P_{rs} = R_s\left(i_{ds}^2 + i_{qs}^2\right) \quad (30)$$

$$P_g = v_{ds}\, i_{dg} + v_{qs}\, i_{qs} \quad (31)$$

$$P_{dc} = P_{em} - P_{rr} - P_{rs} - P_g \quad (32)$$

MECHANICAL MODEL

Drive train of wind mill is divided into two parts. First one is the low speed mass model which represents the blade shaft with J_b as inertia constant and D_b as damping constant. Second one is the high speed mass model which represents the generator shaft with J_g as inertia constant and D_g as damping constant.

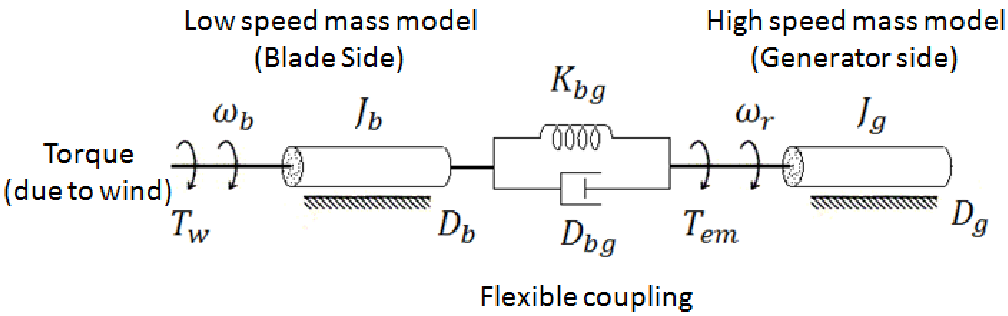

Figure 4: Drive Train Model

Drive train model is denoted by following equation

$$\frac{d\theta_b}{dt} = \omega_b \quad (33)$$

$$\frac{d\theta_r}{dt} = \omega_r \quad (34)$$

$$\frac{d\omega_r}{dt} = \frac{1}{J_g}\left(K_{bg}\left(\theta_b - \theta_r\right) + D_{bg}\left(\omega_b - \omega_r\right) - D_g\,\omega_r - T_{em}\right) \quad (35)$$

$$\frac{d\omega_b}{dt} = \frac{1}{J_b}\left(T_w - D_b\omega_b - D_{bg}\left(\omega_b - \omega_r\right) - K_{bg}\left(\theta_b - \theta_r\right)\right) \quad (36)$$

Where θ_b, θ_r represents the angular displacement and ω_b , ω_r are speed of blades and rotor respectively.D_{bg} and K_{bg} denotes the damping constant and stiffness of the flexible coupling respectively.T_w As wind torque

$$T_w = \frac{P_{out}}{\omega_b} \quad (37)$$

SIMULINK MODEL

Simulink Model with DFIG (Model 1)

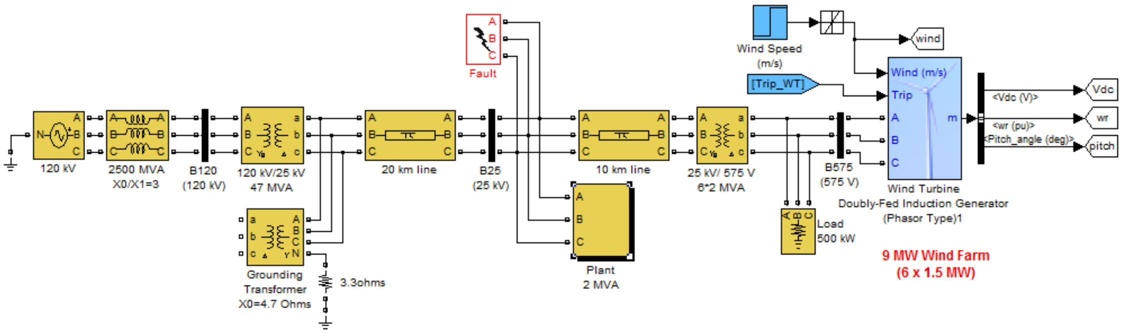

Figure 5: Simulink Model with DFIG

In the wind system, six unit of 1.5 MW DFIG is used so that total generation is 9MW and output voltage is 575V on 60Hz frequency. Output voltage is step up on 25KV through 12 MVA step up transformer and power is supplied to 120KV grid through 30 km transmission line. 10km from the generation side 2 MVA load is present which include 1.68 MW asynchronous motor of 0.93 pf. DC bus capacitor in back to back converter is 6*10000e-6 F [9]. Speed of wind is assumed to be fixed at 8m/s. 5Various faults are generated on the transmission line. Voltage and reactive power at 575 V bus is monitored. These results are compared with second model. In the second model DFIG is replaced by synchronous generator of same rating and limitation.

Simulink Model with Synchronous Generator (Model 2)

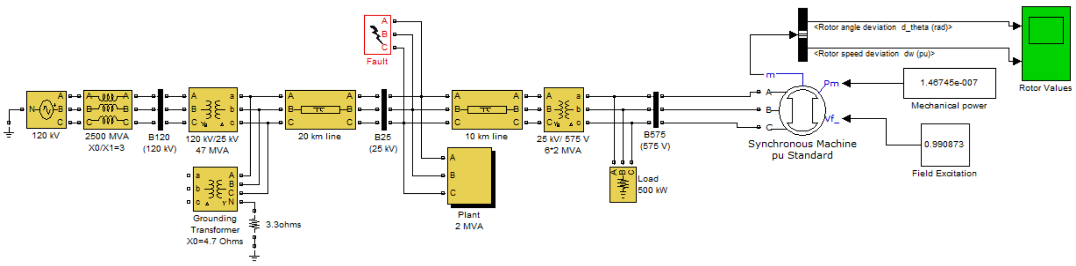

Figure 6: Simulink Model with Synchronous Generator

SIMULATION RESULT

Faults like single line to ground, double line and three phase faults are enabled at the distance of 10km from the generation point on transition time [10 12+9/60]s with [1 0] transition status. At 575V bus Voltage and reactive power of both model is plotted on same graph and comparative study is done.

Case 1: Single Line to Ground Fault

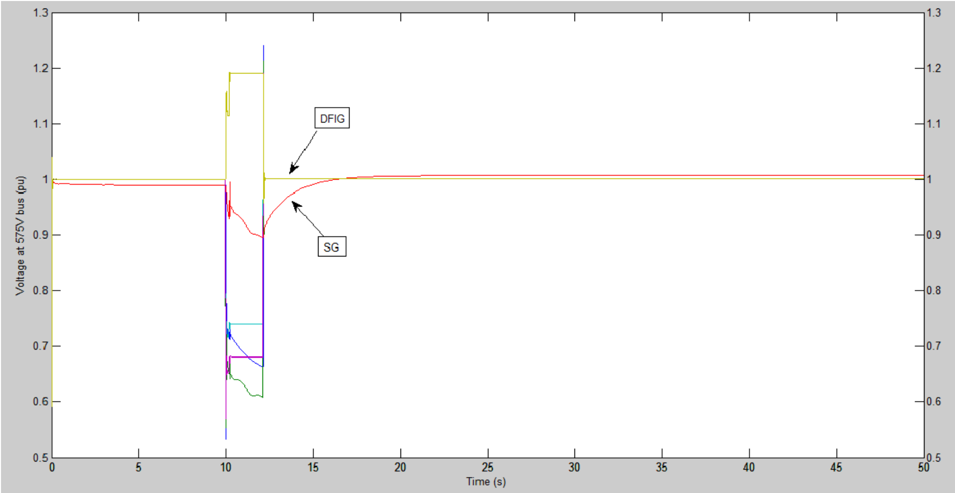

Figure 7: Voltage at 575V Bus for Single Line to Ground Fault

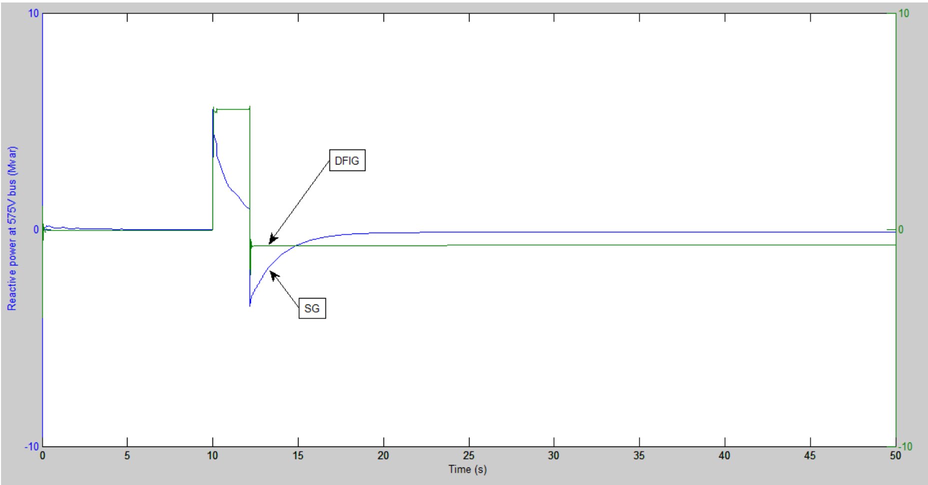

Figure 8: Reactive Power at 575V Bus for Single Line to Ground Fault

Case 2: Double Line Fault

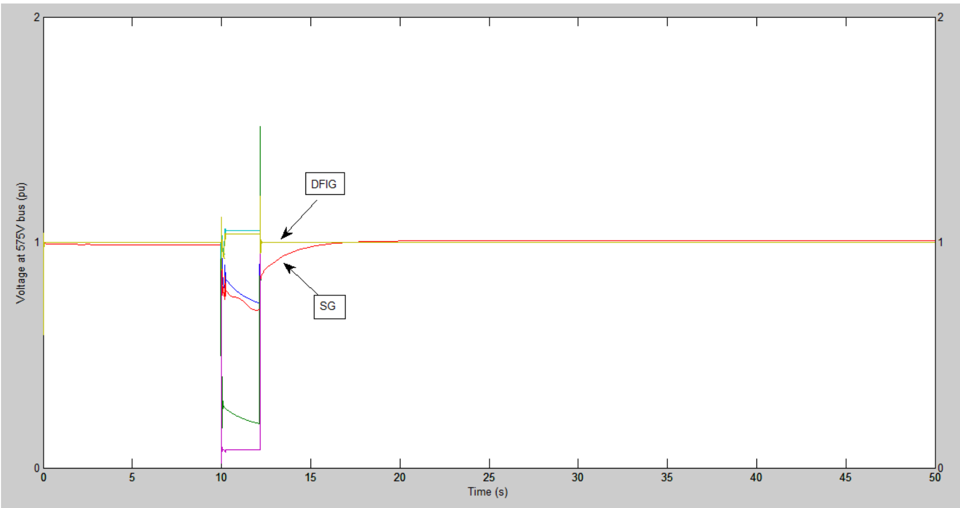

Figure 9: Voltage at 575V Bus for Double Line Fault

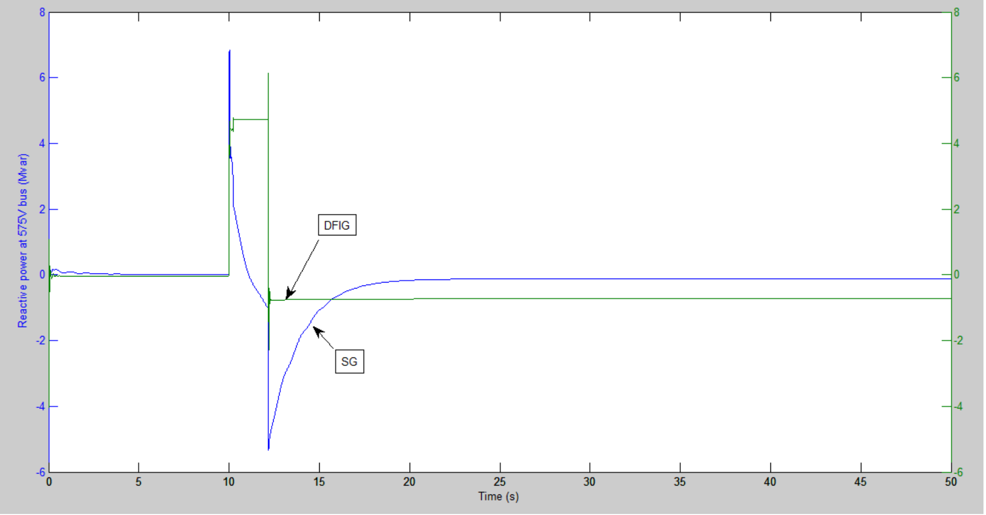

Figure 10: Reactive Power at 575V Bus for Double Line Fault

Case 3: Three Phase Fault

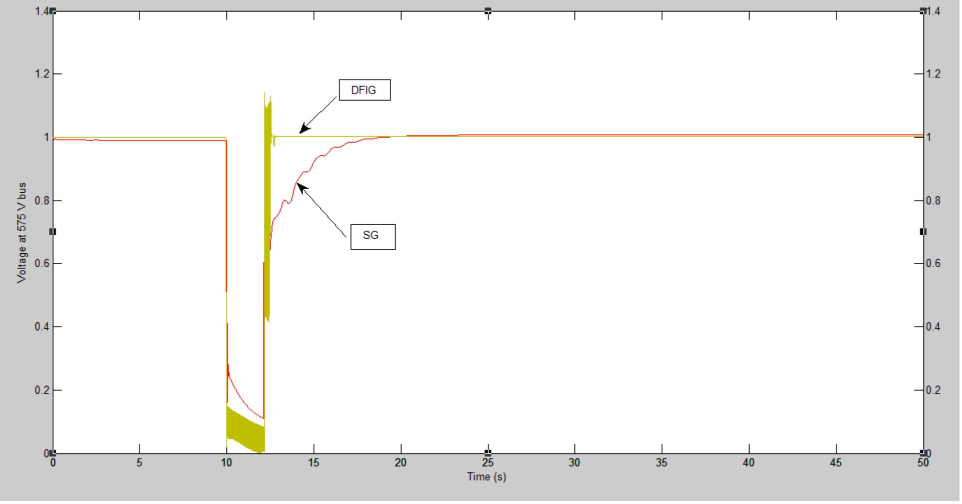

Figure 11: Voltage at 575V Bus for Three Phase Fault

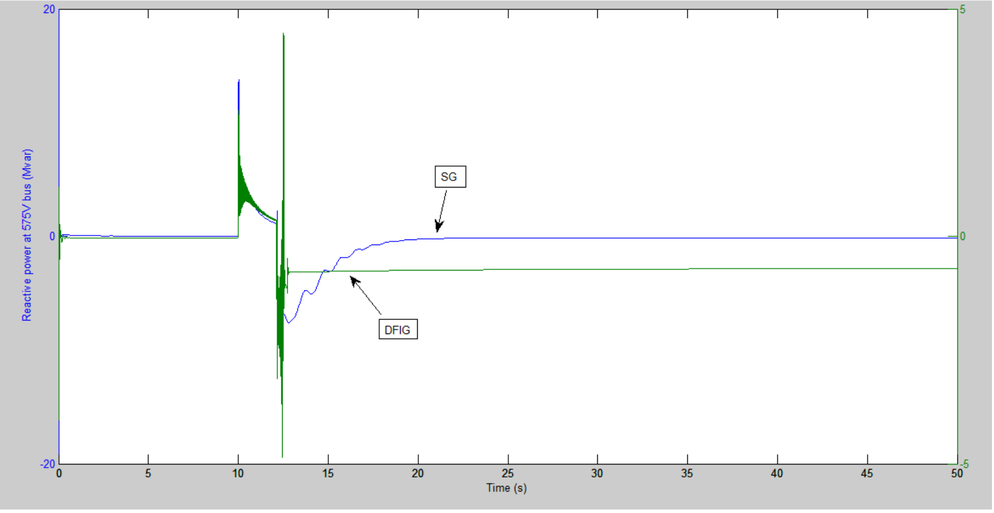

Figure 12: Reactive Power at 575V Bus for Three Phase Fault

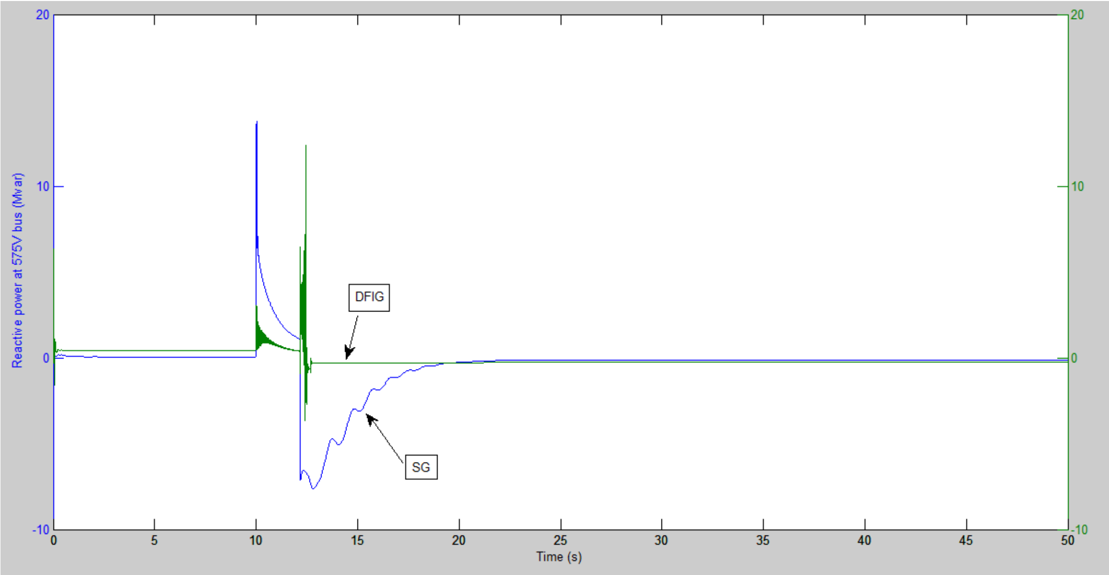

Figure 13: Reactive Power for Three Phase Fault with SVC (Which Supplies the 2200Kvar)

In the above all three cases fig.7, fig.9 and fig.11 shows the voltage at 575V bus for various faults. Fault is enabled at 10s. When the fault is cleared at 12.15s DFIG reaches its steady state value faster than SG. From these figures we show that DFIG shows better response in comparison to synchronous generator in voltage build up. In fig.8, fig.9 and fig.12 shows the reactive power at 575V bus for various faults. In case of DFIG after the fault is cleared reactive power is become negative. Therefore extra source of reactive power is required to fulfil the demand. In fig.13 SVC of appropriate value is connected at the terminals of DFIG to compensate the required reactive power.

CONCLUSIONS

For fulfils the electric power demand in future new techniques are continuously evolving. With the advancement in technology, generation of electricity from the wind power made easier. With the advantages of DFIG explained in pervious section, wind power generation touches new peak.

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REFERENCES

1. Ministry of power, Central electricity authority, *Executive Summary power Sector January* (Government of India, New Delhi, 2015)
2. Sohit Sharma, Rimjhim Sharma, Anil Dubey, Indira Rawat, KG Sharma, Monitoring of pollution for increasing the life span of human beings: Discussion on the causes and control measures of pollution for improving the life of people, *International Conference on Signal Propagation and Computer Technology (ICSPCT)*, July 2014, ISBN 978-1-4799-3140-8
3. Dr. Rishi Muni Dwivedi, *India wind power* 1,(Chennai, Indian wind turbine manufacturers association, 2015)
4. Christine Lines, *Renewable 2014 Global status report* (France REN21 2014 978-3-9815934-2-6)

5. Ch. Eping, J. Stenzel, M. Poller, H. Muller, *Impact of Large Scale Wind Power on Power System Stability*, Glasgow, Germany

6. Mohand Ouhrouche, Transient analysis of a grid connected wind driven induction generator using a real-time simulation platform, *Renewable energy 34 Elsevier* (2009) 801-806

7. By the staff of Festo Didactic, *Principles of Doubly-Fed Induction Generators (DFIG)* edition 1 (Festo Didactic 2015) ISBN 978-2-89640-491-9

8. Pablo Ledesma, Julio Usaola, Doubly Fed Induction Generator Model for Transient Stability Analysis, *IEEE transactions on energy conversion*, Vol.20, No. 2, June 2005, 0885-8969

9. MATLAB Work simulation Simulink Toolbox